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Green roofs and urban sustainability: a study on the eldorado shopping project in São Paulo, Brazil

Telhados verdes e sustentabilidade urbana: um estudo sobre o projeto do Shopping Eldorado em São Paulo, SP

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Abstract
Urbanization in cities has been characterized by an accelerated process, leading to a series of challenges in making cities more sustainable, efficient, and livable for their citizens. In response, the concept of sustainability has been adopted to mitigate negative actions and adapt urban structures. This study investigates the benefits of green roofs as a sustainable solution, focusing on the design of Shopping Eldorado in São Paulo, SP. The methodology included a literature review and documentary research, with a guided visit to the shopping center for analysis of the green roof and data collection on maintenance and benefits. The results highlight green roofs as efficient tools for stormwater runoff management, energy consumption reduction, heat island mitigation, and improved waste management. The conclusion emphasizes the feasibility of green roofs in commercial centers, pointing to significant economic, social and environmental benefits.
Keywords: urban sustainability; sustainable city; nature-based solutions; green roof.

Resumo
A urbanização das cidades tem se caracterizado por um processo acelerado e tem gerado uma série de desafios para tornar as cidades mais sustentáveis, eficientes e habitáveis para seus cidadãos. Em resposta, o conceito de sustentabilidade vem sendo adotado para mitigar ações negativas e adaptar as estruturas urbanas. Este estudo investiga os benefícios dos telhados verdes como solução sustentável, focando no projeto do Shopping Eldorado em São Paulo, SP. A metodologia incluiu revisão bibliográfica e pesquisa documental, com uma visita guiada ao shopping para análise do telhado verde e coleta de dados sobre manutenção e benefícios. Os resultados destacam os telhados verdes como ferramentas eficientes para escoamento de água pluvial, redução de consumo de energia, mitigação de ilhas de calor e melhor manejo de resíduos. A conclusão ressalta a viabilidade de telhados verdes em centros comerciais, apontando para ganhos econômicos, sociais e ambientais significativos.
Palavras-chave: sustentabilidade urbana; cidade sustentável; soluções baseadas na natureza; telhado verde.

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1 Introduction

In the last centuries, human action on Earth has drastically altered the planet's natural processes and flows. Negative activities such as the destruction of forests and vegetation to make way for cities, pollution of rivers and oceans, alteration in nitrogen levels due to intensive land use, and the increase in pollution and accumulation of greenhouse gases in the atmosphere have led scholars to call the new geological epoch as the Anthropocene (Barthel, Isendahl, Vis, Drescher, Evans & Timmeren, 2019). By focusing on the most recent decades, one observes an exacerbating factor of society's negative actions with significant impacts on climate change: urbanization. This phenomenon shows no signs of abating; on the contrary, it is estimated to continue growing due to projections of urban growth. It is estimated that 68% of the global population will live in cities by 2050, indicating an increase of 2.2 billion people in this type of urban structure (UN, 2015).

In response to the adverse situations caused by urban centers, the concept of sustainability is employed to mitigate negative actions and adapt existing structures to better serve society with the available resources (Thornbush, Golubchikov & Bouzarovski, 2013). Although sustainability is often associated with environmental aspects, regarding cities, it is necessary to also encompass economic and social issues and ensure that these three spheres work together for a sustainable city (Kadir & Jamaludin, 2013). To restraint the consequences of high urban expansion, policies and strategies for sustainable development have been created (Egger, 2006), aiming to offer a better quality of life for citizens and social and economic equity, conserve energy, better utilize natural resources, reduce water and air pollution, manage food waste, and promote smart and healthy growth in cities (Sodiq et al., 2019).

Still in response to urban population growth and its negative consequences, sustainable cities seek different tools to assist in managing and adapting to the climate crisis (Hong, Kim, Koo & Kwak, 2012). The pursuit of solutions with relatively low costs compared to extremely expensive systems and technologies, capable of utilizing and optimizing existing infrastructure, has led cities to invest in living organisms such as soils, sediments, and organic matter with multi-functional and adaptable capabilities, leading to the use of Nature-based Solutions (NbS) (Hobbie & Grimm, 2020). Through the provision of ecosystem services (ES), NbS, such as green roofs, have been incorporated into both new and existing buildings (Calheiros & Stefanakis, 2021), proving to be an efficient tool in terms of stormwater runoff, reduced energy consumption, urban heat island effect mitigation, increased biodiversity, and improvement in social well-being (Editors Rosenzweig, Gaffin & Parshall, 2006).

This strategy of innovating in sustainable environment planning improves urban sustainability and brings benefits at different scales, with scientific literature reporting these benefits for decades (Saadatian et al., 2013; Pineda-Martos & Calheiros, 2021). The multiple gains can be categorized into energy-related advantages (e.g., cooling), improvement of air quality (e.g., CO2 sequestration and particulate matter retention), water management (controlling surface runoff), and aesthetic gains, which can yield psychological benefits (Mihalakakou et al., 2023).

Although there is considerable discussion about green roofs and their ecosystemic benefits, less attention is given to their feasibility on roofs of commercial centers or non-residential buildings, such as shopping malls. These locations are strategically favorable for such practices because, in addition to having space, the production of organic waste from food courts is high, which can be decomposed to become compost for plants, thereby increasing productivity.

With the aim of demonstrating the benefits of green roofs in fostering sustainable and smart cities, this study aimed to investigate the Green Roof project at Shopping Eldorado in the city of São Paulo (SP) as one example of tools for building sustainable cities. Thus, the results of this study could be extrapolated to other contexts, types of constructions, and commercial sectors, since the proposal is to combine space availability, opportunity, and sustainable action in the transformation and adaptation of cities.

2 Methodology

The present work is based on a literature review, with the selection of articles obtained through the CAPES Journal Portal from various databases, ensuring the breadth and quality of the sources consulted. The analysis, of an explanatory and descriptive nature, aims to present arguments, foundations, and information on the implementation of green roofs as a tool for promoting the development of sustainable cities. Essential issues regarding the concepts of green roofs and urban sustainability were addressed, as well as the interconnection between these topics and the needs and benefits that each aspect can bring to cities and citizens.

In addition to the literature review, a documentary-based research was conducted at Shopping Eldorado in São Paulo to examine a green roof and gather information about the established maintenance process, as well as the benefits and challenges for implementing the structure. The research was carried out through a guided tour provided by the establishment for individuals interested in learning about the project, which allowed for photographic documentation and access to informational materials.

The visit took place in November 2022, and in addition to specifically going to the rooftop of the building where the green roof is located, the guide also took the group to other areas of the shopping mall to demonstrate not only the process involved in maintaining the green structure but also to explain all the sustainability initiatives of the shopping mall.

3 Results

3.1 Green Roof

Green roofs are urban structures (residential or others) that add ecological value to the tops of buildings. Roofs with different types of plants can serve for human food, promotion of ES, ornamental values, or even cultural (religious) purposes. However, there is currently a discussion on the importance of promoting this strategy to improve urban sustainability, especially in the context of adapting urban spaces to climate change (Li & Babcock, 2014).

The sixth report of the Intergovernmental Panel on Climate Change (IPCC), a document created by the UN on climate change, highlighted cities as one of the main areas to address climate change, since approximately 56% of the world's population lives in urban centers with the prospect of this number continuing to grow in the next decades (IPCC, 2022). The need for cities to take action for climate change increasingly leads cities to adopt the Sustainable Development Goals (SDGs) presented by the UN, focusing on SDG 11 concerning cities, aiming to reduce negative environmental impact per capita, develop projects, and implement initiatives that lead to a decrease in greenhouse gas emissions, improve air and water quality, and manage municipal waste, among others. Considered fundamental actors in climate mitigation and adaptation efforts, urban structures must include topics such as promotion and integration of green infrastructure, preventive action to reduce social vulnerability, evolution in climate change governance with greater participation of civil society, and strategic urban planning (Tischler & Haltermann, 2019).

In this scenario where urban centers are predominantly grey due to numerous constructions, which show no signs of slowing down, professionals from different sectors signal NbS, which are considered living responses where processes and structures are designed to address various environmental challenges while offering economic, social, and ecological benefits (Brasil et al., 2021). NbS are grounded in the act of learning from, being inspired by, and emulating nature, with a crucial understanding of the environment and natural processes to harness the strength of ecosystems as infrastructure to provide services that benefit the city as a whole (structure and actors) (Stefanakis, Calheiros & Nikolaou, 2021). Pearlmutter et al. (2020) add that to combat the effects of climate and grey infrastructure, the integration of NbS and green infrastructure is essential, a strategically planned network for delivering ecosystem services, to increase the presence of nature in cities through the formulation of innovative strategies.

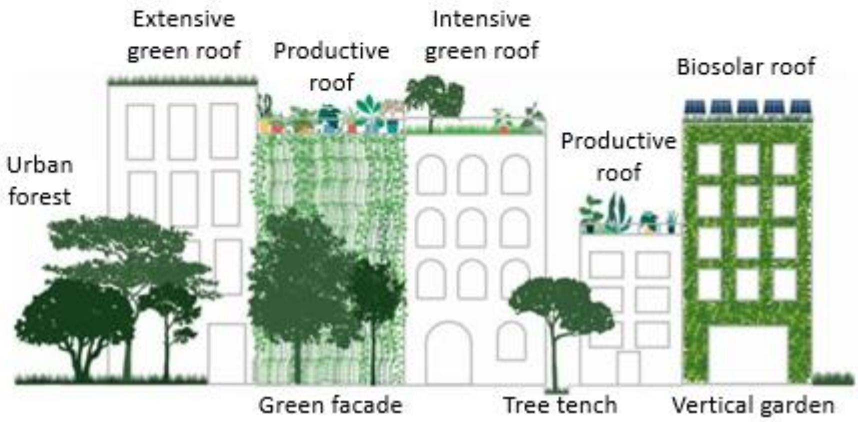
Among the types of NbS are green roofs, parks, urban forests and open spaces, community gardens, stormwater ponds, bioretention basins, riparian zones, and structures for habitat restoration and protection (Hobbie & Grimm, 2020). However, given the limited availability of space, there is a concern to innovate and optimize open areas. In response to this situation, there is a movement towards the use of rooftops and roofs of low-rise buildings for the implementation of green roofs, which can result in savings, aid in climate mitigation, improvement in people's quality of life, and contribution to social actions (Wright, Lytle, Santillo, Marcos & Mai, 2021). NbS, when integrated into buildings, can be presented in three spheres: Green building spaces, Green building materials, and Green building systems, with the latter encompassing green roofs as it is classified as a system that aims to include vegetation in its environments, so that plant strips and living walls are also included in this classification (Pearlmutter et al., 2020).

Green roofs, also referred to as eco-roofs, living roofs, natural roofs, suspended gardens, among others (Rogers, 2013), despite gaining prominence in recent decades, have one of their earliest appearances dating back to 2500 BC in Mesopotamia, evidenced by records of buildings with stepped shapes where it was possible to install different vegetation at various levels, while in Brazil, the first building with vegetative cover appeared in the 1930s in Rio de Janeiro, at the then Ministry of Education and Health (Filho, Reis-Alves, Schueler & Rola, 2015). Unlike the early appearances when climate crisis or urban center densification were not yet topics of discussion, roofs are now seen as structures capable of generating direct and indirect benefits for improving the quality of life in cities and contributing to carbon sequestration, reduction of heat islands and energy consumption, stormwater runoff, rainwater harvesting, and restoration of degraded ecosystems (Sousa, Sousa, Magalhães Junior, Nunes, Faria & Faria, 2021).

In addition to the different nomenclatures, the structures in question can also be classified as extensive, semi-intensive, and intensive depending on the vegetal composition and maintenance specifications (Alves, Bezerra, Silva Filho & Souza, 2021). For a better understanding of the existing varieties, Calheiros and Stefanakis (2021) created Figure 1.

Figure 1

Presence of nature-based solutions in constructions.



Source: Adapted from Calheiros and Stefanakis (2021).

According to the authors, intensive green roofs feature a wide variety of plant species, ranging from small to larger plants such as grass, shrubs, and trees, which require maintenance similar to that of a garden concerning fertilization, irrigation, and accommodation. Due to their sturdier specimens, they require a greater quantity and depth of substrate, typically exceeding 15 cm (Alves, Bezerra, Silva Filho & Souza, 2021). Extensive green roofs consist of smaller, lightweight, yet resilient plants capable of withstanding low water availability, harsh winters, and wind (Sousa, Sousa, Magalhães Junior, Nunes, Faria & Faria, 2021). Due to their characteristics, they require less maintenance as well as substrate, which varies between 5 and 15 cm; however, due to their smaller size, they support less rainfall load (Alves, Bezerra, Silva Filho & Souza, 2021). Although not represented in Figure 1, semi-intensive roofs are characterized by medium-sized plants that alternate between extensive and intensive systems (Sousa, Sousa, Magalhães Junior, Nunes, Faria & Faria, 2021) and are typically composed of a substrate layer that usually ranges from 12 to 25 cm (Calheiros & Stefanakis, 2021). According to Alves, Bezerra, Silva Filho & Souza (2021), implementation and maintenance costs can make green roofs less attractive, especially in drier regions where greater irrigation is required. In this scenario, consideration of species capable of surviving with less water over a longer period is necessary.

The composition and quantity of each element may vary among different structures; however, generally, green roofs are comprised of vegetation, substrate, filtering layer, drainage layer, protective layer, root barrier, insulation layer, waterproofing membrane, and conventional roof platform (Morais et al., 2021).

3.1.2 Economic, social, and environmental benefits of green roofs

The various benefits that green roofs can bring in terms of economic, social, and environmental aspects have led several countries to join this movement of change in urban centers and install this type of structure (Shafique, Kim & Rafiq, 2018). In addition to helping reduce energy consumption, heat island effect, carbon sequestration, and improving air quality (Seyedabadi, Eicker & Karimi, 2021), the use of idle spaces on buildings can lead to a transformation in the visual identity of cities, as the impermeable surface area of buildings in most cities ranges from 40 to 50% (Calheiros & Stefanakis, 2021).

Making buildings greener also contributes to offsetting the damage they bring, as according to the UN, based on reports from the International Energy Agency, it is estimated that building operation and construction sector together account for 38% of global carbon dioxide (CO2) energy emissions (UNEP, 2020). Although there are cities that are signatories to the World Green Building Council's Net Zero Carbon Buildings Commitment, only 29 cities have committed to the cause, including two from South America, Medellín and Santiago de Cali in Colombia (WGBC, 2016). For this scenario, green roofs can be a solution in terms of carbon footprint and lower energy consumption.

Buildings with the potential for implementing a green roof can benefit from a series of sustainability-oriented advantages, generating economic, social, and environmental gains for cities. Starting with the economic perspective, which can be perceived through the performance of roofs directly on the buildings they are on, there are studies demonstrating that the vegetation and soil of green roofs cool the roof surface and the surrounding air, acting as thermal insulation and reducing heat transfer to the interior space (Sproul, Wan, Mandel & Rosenfeld, 2014). Since the temperature inside buildings undergoes smaller changes, the demand for air conditioning or heating is lower, resulting in lower electricity consumption and therefore less expenditure. By contributing to the sequestration of CO2 and consequent improvement in air quality, although not as evident, green roofs can generate a social cost of carbon (Teotónio, Silva & Cruz, 2018). This expense identifies the economic cost of an additional ton of CO2 emitted into the atmosphere on social welfare activities, meaning it is the value of the damages caused at a given moment, which is important information for the formulation of public policies (CEPAL, 2019).

While some benefits can be easily monetized, there are others considered intangible as there is no clear and easy way to quantify and assign financial value to them, such as well-being, noise reduction, ecological preservation, property value appreciation, and improvement in the visual design of the city (Shafique, Kim & Rafiq, 2018). The perception and quantification of benefits, according to Teotónio, Silva & Cruz (2021), can also be affected in terms of the scale of analysis, as depending on the type, it may only be perceived at a broader level (city) and not at a smaller level (building). The authors give an example of the insignificant contribution that a 200 m2 green roof area can have on improving the air quality of a city.

As an example of carbon sequestration monetization, Hong, Kim, Koo & Kwak (2012) established and analyzed different scenarios and compositions of green roofs in schools, which demonstrated at various levels that the amount of CO2 absorption could result in carbon credits and thus monetary value.

Of the three spheres governing sustainability, the environmental sphere is probably where the benefits are most easily perceived, which can vary widely, such as managing stormwater runoff, improving air and water quality, reducing building energy consumption, reducing noise pollution, extending the life of roofs, mitigating heat island effects, and increasing green spaces in urban centers (Vijayaraghavan, 2016). Given the breadth of the topic and in order to elaborate in more detail on how cities and citizens can benefit environmentally, this work will address three issues: energy usage, stormwater runoff, and heat island effects.

By adding thermal resistance to buildings and reducing heat exchange between the structure and the indoor environment, green roofs are capable of cooling facilities during periods of warmer weather and consequently reducing energy consumption for cooling (Shafique, Kim & Rafiq, 2018). This phenomenon can be observed in both new and older buildings; however, it is in the latter type where there is generally a greater reduction in energy usage, as they tend to have a thinner layer of thermal insulation, resulting in greater heat transfer

(Cascone, Catania, Gagliano & Sciuto, 2018). In order to demonstrate the energy efficiency of green roofs compared to buildings without this structure, Liu and Baskaran (2003) conducted a study in Canada comparing the two constructions. Due to the strong influence of solar radiation on the heat flux of concrete, the green roof showed excellent performance during spring and summer, as it was able to improve thermal performance by providing shading, insulation, evapotranspiration, and thermal mass.

During periods of heavy rainfall, trees and plants are important allies for cities in reducing the risk of flooding. While the water that falls on trees is quickly evaporated and returns to the atmosphere, the soil has the function of absorbing it and gradually releasing it into streams or providing a pathway for it to reach the groundwater table (Editors, Rosenzweig, Gaffin & Parshall, 2006). In densely populated areas such as urban centers, where rainwater finds few absorption areas as it falls directly onto pavements, green roofs also function as a sort of purifier by absorbing heavy metals such as copper, zinc, cadmium, and lead (Shafique, Kim & Rafiq, 2018).

Between 2006 and 2010, Zhang, Miao, Wang & Liu (2015) analyzed the absorption and quality of rainwater from two areas in Chongqing, China, one with a green roof and the other without vegetative cover installed adjacent to a school. The traditional roof showed an average of 0.42 mm of water retention, while the green roof absorbed an average of 11.61 m during the same period. Regarding the pH of the water, the average value obtained on the green roof was 6.84, which falls within the standard range (6.0 - 9.0), whereas the other roof exhibited a more acidic pH of 5.61. Considering that Chongqing is a region typical of acid rain (pH < 5), which brings damage to soils and physical structures, the study showed that green roofs can help reduce the acidity of rainwater.

When considering the three fundamental elements of sustainability—economic, environmental, and social—the latter is arguably the most challenging sphere to link to the benefits of green roofs. This inconvenience arises from the fact that social aspects are closely tied to visual and aesthetic considerations, as well as well-being, which are intangible and non-quantifiable (Shafique, Kim & Rafiq, 2018). However, the social aspects and quality of life benefits for citizens can be explained through the value of ES, which were precisely created to demonstrate the benefits of ecosystems to society (Kotzen, 2018). The concept of ES, although still not widely discussed, has been increasingly used in the strategic realm of public policy creation, considering the relationship of the topic with city sustainability, natural resource use, climate change mitigation, ecosystem restoration, citizen well-being, and city aesthetics (Hauck, Görg, Varjopuro, Ratamaki & Jax, 2013).

ES, to better categorize the various benefits they are associated with, are divided by some authors into four categories: a) regulation services: these concern natural resources (air, water, soil quality), stormwater management, waste disposal, and disease regulation. b) provisioning services: encompass consumer goods (food and medicine), biomass production, and raw materials for energy resources. c) support services: are related to elements that contribute to the conservation of biological factors such as species habitat, maintenance of genetic diversity, soil formation, and nutrient and water cycling. d) cultural services: include ethical values, aesthetic appreciation and inspiration, recreation, well-being, mental and physical health, education, and knowledge. (Kotzen, 2018; Spangenberg, Gorg, Truong, Tekken, Bustamante & Settele, 2014; Kabisch, 2015).

When addressing the aesthetic and quality of life aspects that green roofs bring to society, it is noted that they fall under cultural services, as they are linked to non-material benefits (Kotzen, 2018). Even though there are decision-makers who argue that green spaces are superfluous items and should not be a priority within policies, studies indicate a direct relationship between green areas and the mental and physical health of individuals (Kondo, Fluehr, McKeon & Branas, 2018). Furthermore, Bratman et al. (2015) point out several benefits that green areas bring to human well-being, as areas with plants and vegetation can mitigate and improve mental illnesses, stress, and even cognitive functions in people of various age groups, prompting some cities to include this issue in public agenda discussions and to rethink the structures and design of urban centers.

Additionally, green roofs can bring social value by being used for food production, albeit on a smaller scale compared to traditional methods of production in large areas and directly in the soil (Shafique, Kim & Rafiq, 2018). The use of buildings for this purpose not only allows for a reduction in the distance between producer and consumer, leading to less food loss, but also results in educational and cultural enrichment regarding citizens' engagement with a system not commonly found in urban centers. Often, because it is located in more remote municipalities, this leads to a lack of contact and knowledge among people about how the food they consume is produced (Walters & Midden, 2018).

As green roofs are not only linked to ecological aspects but also present interconnected benefits with widely spread sustainability concepts, encompassing economic, social, and environmental dimensions, they emerge as allies for urban centers and citizens in fostering businesses, mitigating the effects of climate change, and promoting a better quality of life. However, for these structures to become even more prevalent in cities in pursuit of a sustainable agenda capable of intelligently utilizing all available resources, it is necessary for various actors in society to get involved (Calheiros & Stefanakis, 2021).

3.2 Green Roof of Eldorado Shopping Mall

The green roof of Shopping Eldorado was created in 2012 as a visionary solution for the proper disposal of the 164 tons of organic waste generated monthly in the food court, with the amount reaching approximately 2,000 tons annually.

The waste treatment process begins in the food court itself, more specifically in a sort of bay, where employees separate food and items left on trays into organic waste (brown bag) and recyclable (green bag).

After separation, the organic waste is taken to the internal composting area, where it is sorted (checking for any other waste besides organic) and then inserted into the composting machine (Figure 2), which is an old machinery purchased from a scrapyard. In the machinery, along with the waste, the following are added: a) peat: responsible for accelerating the food decomposition process; b) lime: aids in the drying of the food, through a chemical reaction that occurs during the mixing of the elements; c) sawdust: reinforces the food drying process and also reduces the strong odor of decomposing organic matter.

Figure 2

Composting System at Eldorado Shopping Mall.

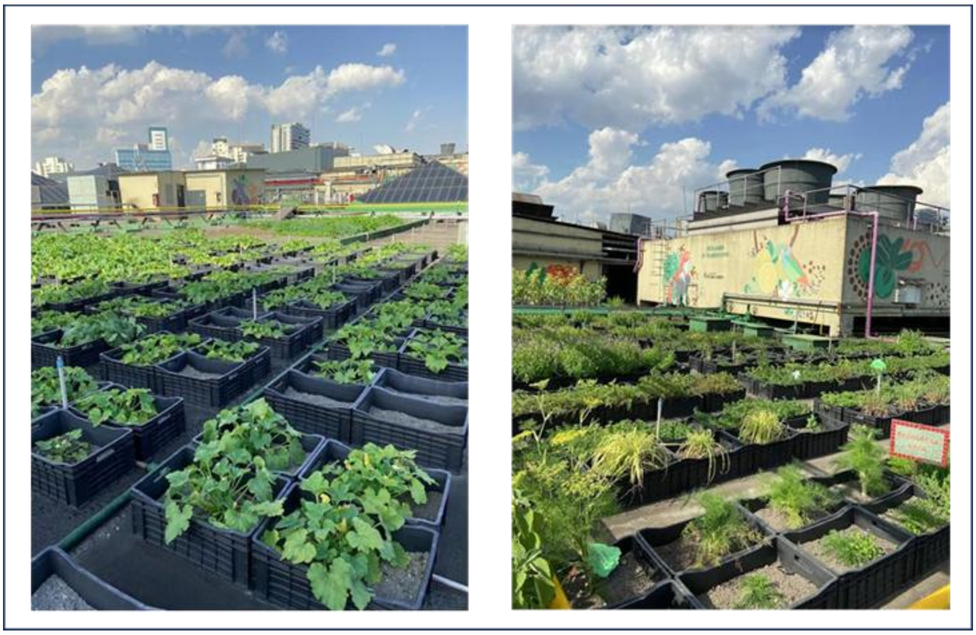
Source: Authors' collection (2023).

From composting, the fertilizer to be used on the green roof is obtained. Considering that the amount of fertilizer generated from composting all organic material would be much higher than what the vegetation needs, the shopping mall uses only 20% of the waste, while the remainder is sent to the company Biomix, which also uses them for composting and later sells the fertilizer.

The green roof is primarily composed of vegetables and greens, with some fruit trees and flowers as well (Figure 3). In the 6,000 m² area, around 40,000 vegetables and greens are produced annually, comprising approximately 30 types such as lettuce, arugula, zucchini, kale, parsley, herbs, among others. All the food produced is distributed among the shopping mall employees, who rotate to the roof when the crops are ready and participate in the harvesting process.

Figure 3

Green roof - vegetables and greens - herbs and flowers.



Source: Authors' collection (2023).

The reasons that led the shopping mall to implement the green roof were basically twofold: sustainability and economic considerations. In light of municipal law 13,478, from 2002, all Large Waste Generators (LWG), meaning commercial establishments that generate more than 200 liters of waste per day, must contract a responsible company to carry out the services of collection, transportation, treatment, and final disposal of the generated waste; the shopping mall is responsible for waste disposal, and until 2012, it was entirely destined for landfills.

Following the implementation of the project, the waste began to be composted, and the surplus was sent to a third-party company responsible for collecting the material within the shopping mall itself, leading the enterprise to reduce the amount of material sent to landfills, from 86% (2013) of the total waste to 29% (2021). In terms of benefits, the green roof also contributed to reducing the temperature by around 6°C in the inter-floor space of the building, resulting in lower energy consumption.

In order to improve the sustainability actions of the mall every year, the management aims to achieve zero landfill, which it intends to accomplish by adapting to the market and introducing new and innovative projects.

4 Analysis of the Results

According to the literature review conducted, it is understood that although green roofs are recognized as a Nature-based Solution (NbS) that significantly contributes to urban sustainability, especially in response to climate change (Li & Babcock, 2014; IPCC, 2022), the implementation of these structures faces challenges, including initial and maintenance costs, particularly in drier regions (Alves, Bezerra, Silva Filho & Souza, 2021). Furthermore, the composition and maintenance of green roofs vary depending on the type, as they can be extensive, semi-intensive, or intensive, each with different substrate and care requirements (Calheiros & Stefanakis, 2021).

Shafique, Kim & Rafiq (2018), in their literature review, also highlight the multiple benefits of green roofs, including their impact on urban heat sensation, improvement of air quality, stormwater runoff management, reduction of energy consumption, as well as cultural services related to well-being and mental health. However, their work does not situate green roofs within the context of Nature-based Solutions (NbS) and emphasizes a greater need for detailed experimental investigation, specifically addressing the impacts on hydrology and global warming mitigation.

Similarly, another literature review by Vijayaraghavan (2016) identifies comparable benefits of green roofs, but highlights the importance of integrating these structures with other management practices and optimizing components for different climatic conditions. Additionally, the author emphasizes the lack of analyses concerning the life cycle and costs in each geographic location to understand the real scenario and enable better decision-making by consumers and policymakers.

In line with the findings from the present literature review, the green roof project at Eldorado Shopping indicates a reduction in the building's internal temperature, leading to lower energy consumption, and addresses efficient waste management with a consequent reduction in landfill disposal. Therefore, to further deepen the efficacy and returns of the project, it would be highly valuable to conduct future analyses encompassing additional parameters, including well-being and aesthetics, as well as life cycle assessments and cost-benefit analyses.

5 Final Considerations

Based on the literature review and field documentary research, it was found that green roofs are a tool for promoting sustainable and smart cities, especially in megacities. They offer benefits such as reducing the urban heat island effect, improving air quality, managing stormwater, and decreasing energy consumption—problems that are significantly pronounced in large urban centers. However, their implementation faces challenges such as high initial and maintenance costs, especially in dry regions, and the need for adaptation according to the type of roof. Examples like the green roof at Eldorado Shopping in the megacity of São Paulo highlight these benefits, demonstrating reduced internal temperatures and energy consumption, as well as efficient waste management. Future studies should explore parameters such as well-being, aesthetics, life cycle assessments, and cost-benefit analyses to gain a more comprehensive understanding of the impacts and returns of this initiative.

Given the projection that the urbanization movement will continue to grow in the coming decades, it is essential for cities to find solutions to mitigate problems resulting from this unchecked growth and thus contribute to the Agenda 2030, more specifically concerning this work, to SDG 11 related to sustainable cities and communities.

Within the movement to ensure that cities are sustainable in various aspects, green roofs emerge as an innovative solution as they bring adaptability with them. Knowing that cities will continue to expand and that green areas bring numerous benefits, finding unused spaces and transforming them into environments capable of improving quality of life, helping to mitigate local temperatures, assisting in reducing flooding, providing food, and saving resources is innovative.

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